New Gogny-like interactions with tensor-isospin term

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Despite their relevance in microscopic interactions, the tensor terms are usually neglected when effective nucleon-nucleon (N-N) interactions and theories are used. In these last years, the interest on the tensor terms of the effective N-N interaction has increased because the inclusion of these terms improves the description of the single particle (s.p.) energies of some isotope or isotone chains when the Hartree-Fock theory is used [1–4]. In this work [5] we have proposed an alternative approach to select the strength of the effective tensor forces by considering global properties of the nucleus. The most important tensor component of the microscopic N-N interaction is that related to the tensor-isospin channel whose long range behaviour is dominated by the exchange of a single pion. Since the pion is the lightest meson, the range of the tensor-isospin term is longer than the ranges of the other terms of the N-N interaction. For these reasons we have chosen to consider, in our effective interactions, only tensor-isospin terms with finite range. The tensor-isospin term of our effective interaction is based on the analogous term of the microscopic Argonne V18 interaction. We have multiplied the radial part of this term by a function which simulates the effect of the short-range correlations [6]. In our work, the radial part of the tensor-isospin term has the form

$$v_6(r) \;=\; v_{6,\mathrm{AV18}}(r)\;\left[1 \,-\, \exp\left(-\,b\,r^2\right)\right]\,, \qquad (1)$$

where we have indicated with r the distance between the two interacting nucleons, with $v_{6,\mathrm{AV18}}$ the radial function of the Argonne V18 tensor-isospin potential, and with b a free parameter. The changes in the tensor-isospin term produced by chosing different values of b are shown in panel (a) of Fig. 1, where we present the Fourier transformed function $V_6(q)$, defined by the equation

$$V_6(q) S_{12}(\mathbf{q}) = \int \mathrm{d}^3 r \exp\left(i\mathbf{q}\cdot\mathbf{r}\right) v_6(r) S_{12}(\mathbf{r})$$
$$= -4\pi \int \mathrm{d}r r^2 j_2(qr) v_6(r) S_{12}(\mathbf{r}). \quad (2)$$

In the above equation r and q indicate the moduli of $\mathbf{r}$ and $\mathbf{q}$, and we used the definition of the tensor

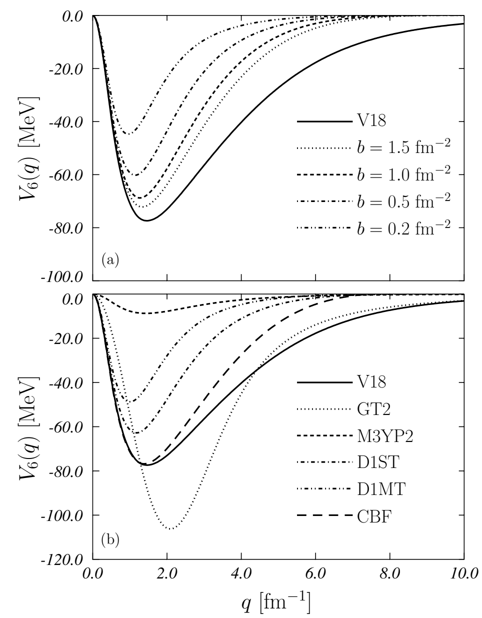

Figure 1. Momentum dependent term of the tensor force, for various parameterizations.

operator

$$S_{12}(\mathbf{r}) \;=\; 3\frac{[\boldsymbol{\sigma}(1)\cdot\mathbf{r}]\,[\boldsymbol{\sigma}(2)\cdot\mathbf{r}]}{r^2} \;-\; \boldsymbol{\sigma}(1)\cdot\boldsymbol{\sigma}(2)\,, \; (3)$$

where $\boldsymbol{\sigma}$ are the usual Pauli spin matrices.

The results presented in the panel (a) of Fig. 1 show that the correlation effects decrease the strength of the bare tensor force. The smaller is the value of b, the more extended in r space is this effect, therefore the function to be integrated in Eq. (2) becomes smaller.

The first step of our study consisted in identifying an observable very sentitive to the tensor force with the aim of using it to determine the strength of this part of the effective interaction. We have conducted this study by investigating the excitation spectra of the ^{12}C , ^{16}O , ^{40}Ca , ^{48}Ca , ^{90}Zr and ^{208}Pb nuclei within the discrete phenomenological RPA approach. The most interesting case is the excitation of the 0^- states showing common characteristics in all the nuclei we have considered.

We summarize in Fig. 2 the results obtained for the energies of the lowest 0^- excitations in the nuclei we have investigated. In this figure,

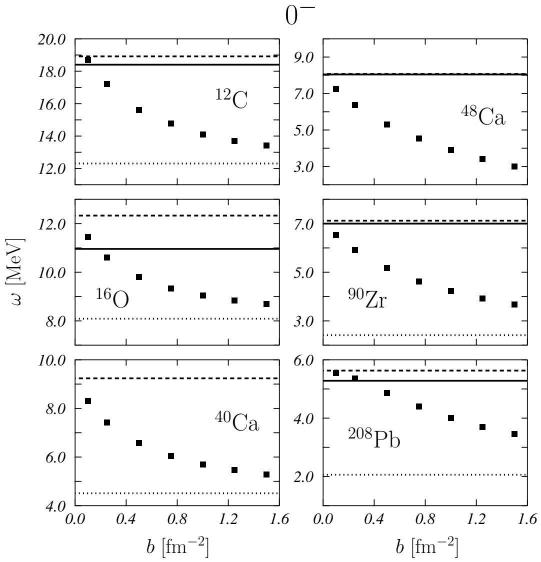

Figure 2. The excitation energies of the lowest 0^- states for various nuclei as a function of the value of the parameter b.

the squares indicate the values of the 0^- excitation energies obtained by adding the tensor term of Eq. (1) to the Landau-Migdal force, for different values of the parameter b, indicated in abscissa. The horizontal dashed lines indicate the values obtained without tensor term, while the dotted lines show the values obtained by using the full tensor term of the Argonne V18 interaction. The full lines show the experimental values [7,8]. We observe that the effect of the tensor term is always actractive. The values of these energies monotonically, and smoothly, descrease from the dashed to the dotted lines with the increase of the value of b, as we have naively expected. The remarkable sensitivity of the 0^- excitation energies to the presence of the tensor force, and their smooth behaviour with respect to the changes of its strength, make these energy values particularly suitable to be chosen as experimental benchmarks to select the strength of the tensor terms in effective interactions.

We have constructed two new interactions to be used in HF plus RPA calculations by adding a tensor term of the type (1) to the D1S [9] and D1M [10] parameterizations of the Gogny interaction. We have chosen the value of the parameter b of Eq. (1) to reproduce the experimental value of the 0^- excitation energy in ^{16}O and the splitting of the s.p. energies of the $1p_{1/2}$ and $1p_{3/2}$ neutron states of the same nucleus. We label D1ST and D1MT the new interactions we have constructed starting from the D1S and D1M forces respectively. We found for the parameter b the value of 0.6 fm^{-2} for the D1S force and of 0.25 fm^{-2} for the D1M force and we modified the spin-orbit terms from 130 to 134 MeV for D1ST interaction and from the 115 to 122.5 MeV for the D1MT.

The tensor terms of the D1ST and D1MT interactions are shown in panel (b) of Fig. 1 by the dashed-dotted and dashed-doubly-dotted lines respectively. In this figure they are compared with the tensor-isospin term of the microscopic Argonne V18 interaction. For construction the effective tensor terms are smaller than that of the bare N-N interaction. More interesting is the comparison with the long dashed line which has been produced by multiplying the bare interaction with the short-range correlation function obtained by Correlated Basis Function calculations [6]. The remarkable difference between this line and those of the D1ST and D1MT forces indicates that our procedure includes in the effective tensor term not only the effects of the short-range correlations, but also some other many-body effects that the microscopic calculations consider explicitly. In the same panel we make a comparison with other two tensor terms of finite-range interactions used in the literature, the GT2 [2] and the M3YP2 [11] forces. The tensor term of the GT2 is constructed to have the same volume integral of the Argonne V18 tensor force. The strength of this tensor force is much larger than those of the tensor forces we have obtained. On the opposite, we observe that the tensor term of the M3YP2 force is much smaller.

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